NATIONAL RENEWABLE ENERGY LABORATORY

Strategies for International Cooperation in Support of Energy Development in Pacific Island Nations

Mackay Miller, Phil Voss, Adam Warren,
Ian Baring-Gould, and Misty Conrad

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Technical Report
NREL/TP-6A20-53188
May 2012

Contract No. DE-AC36-08GO28308

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Prepared under Task No. IGIN.1001

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Contract No. DE-AC36-08GO28308

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Acknowledgments

This work was funded by the U.S. Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy (EERE). Dolf Gielen and Mirei Isaka of the International Renewable Energy Agency's Innovation and Technology Cooperation Center provided valuable insights and helpful suggestions. The authors wish to thank Scott Gossett and Mary Lukkonen of NREL for their editorial support.

List of Acronyms

ADB	Asian Development Bank
CREDP	Caribbean Renewable Energy Development Programme
DOE	U.S. Department of Energy
DOI	U.S. Department of Interior
EC-LEDS	Enhancing Capacity for Low Emission Development Strategies
EDIN	Energy Development in Island Nations
EE/RE	energy efficiency and renewable energy
GDP	gross domestic product
GEF	Global Environment Facility
GOI	Government of Indonesia
GPH	Government of the Philippines
HCEI	Hawaii Clean Energy Initiative
Hz	hertz
IRENA	International Renewable Energy Agency
IITC	IRENA Innovation and Technology Center
LCOE	levelized cost of energy
MSW	municipal solid waste
NREL	National Renewable Energy Laboratory
OAS	Organization of American States
OIA	Office of Insular Affairs (U.S. Department of Interior)
PIC	Pacific Island countries
PIGGAREP	Pacific Islands Greenhouse Gas Abatement through Renewable Energy Project
PIREP	Pacific Islands Renewable Energy Project
PPA	Pacific Power Association
PV	photovoltaic
RET	renewable energy technology
SODAR	sonic detection and ranging
SPC	Secretariat of the Pacific Community
SPREP	Secretariat of the Pacific Regional Environment Programme
SWH	solar water heating
T&D	transmission and distribution
UNDP	United Nations Development Programme
USVI	U.S. Virgin Islands
VAWT	vertical axis wind turbines
WTE	waste to energy

Executive Summary

The U.S. Department of Energy's National Renewable Energy Laboratory (NREL) has been partnering with island communities around the world to address the technical, policy, social, and economic hurdles to deploying energy efficiency and renewable energy technologies (RETs) on small, islanded systems. The lessons learned from these partnerships are briefly summarized in this document with the goal of supporting the International Renewable Energy Agency (IRENA) as it develops near-term and longer-term strategies for island RET deployment through its Islands Initiative.

Lessons learned are organized into three sections:

- Considerations for energy technologies in island settings
- The human dimension of deployment
- Strategies for international cooperation in 2012 and beyond.

While island energy initiatives are numerous as of the first quarter of 2012, many challenges remain in efforts to shift away from fossil-based energy sources. RET deployment in island settings is characterized by a range of technical, social, and financial barriers that are unique to each island context. Significant challenges remain in the realms of human capital development, resource assessment, and financial and technical innovation. Drawing primarily on the experience gained through NREL partnerships, this report seeks to highlight the opportunities and challenges that are likely to shape island energy deployment over the short- and medium-term future.

Table of Contents

List of Figures

List of Tables

1 Introduction

Island communities worldwide face great challenges in achieving reliable, affordable, and secure energy for power and transportation needs. In spite of often having a relative abundance of renewable energy resources, most island countries remain highly dependent on imported fossil fuels to meet their energy needs. Due to the remoteness and relatively small size of most islands, imported fuel is typically very expensive. The expense, volatility in price, and potential for disruption in supply of fuel has a significant effect on island economies. According to 2010 Asian Development Bank (ADB) economic data for Pacific Island countries (PICs), 2009 gasoline prices ranged from about US$0.80 to more than US$1.50 per liter. Diesel ranged approximately from US$0.70 to US$1.40 per liter, resulting in electricity tariffs from about US$0.15/kWh to well over US$0.50/kWh.[1] PICs with a single supplier ultimately pay higher premiums for fuel than those with price competition. In this context of relatively expensive conventional energy, deployment of renewable energy technologies (RETs) can convey substantial economic benefits. Yet while there have been efforts to increase RET deployment in PICs over the past few years, the penetration level in the region remains relatively low.[2]

Through a range of workshops, policy forums, and targeted analytical efforts, the International Renewable Energy Agency (IRENA) is actively working to accelerate the adoption of RETs in island settings. In October 2011, IRENA held a workshop in Sydney, Australia convening energy experts from the region to develop a work program[3] for the Pacific. The resulting program was subsequently discussed and accepted at the Pacific Leaders Meeting in January 2012 in Abu Dhabi, where leaders and representatives of Pacific island countries and territories outlined[4] a range of critical steps for achieving the goals of the work program. The communiqué issued at the Pacific Leaders Meeting also welcomed IRENA efforts to create a platform for up-to-date RET information, map the "Renewable Energy Readiness" across the Pacific island basin, assist in capacity building initiatives, and a range of other activities. This report aims to summarize NREL island-based activities in order to support the various activities of the IRENA Islands Initiative.

Deploying RETs for electricity generation in the Pacific region faces unique challenges. The initial cost of implementing RETs can be high as the technology (and typically expertise) must be imported, although levelized cost of energy (LCOE) is likely to be competitive with conventional fuels due to lower life cycle costs. Electric grid reliability issues and the amount of available transmission capacity may require significant upgrades prior to interconnection of intermittent RETs for utility-scale power applications. The system characteristics of existing baseload generation are also a factor. For example, high-speed generators can balance the intermittency of wind or solar photovoltaic (PV) power better than low-speed generators. In addition, the presence of appropriate control systems and training for grid operators may be necessary for large-scale RET systems.

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[1] *Pacific Economic Monitor*. Asian Development Bank. July 2010. http://www.adb.org/Documents/Reports/PacMonitor/pem-jul10.pdf. Accessed March 14, 2012.

[2] In most island communities, transportation represents a significant source of fuel demand. While the displacement of fossil-based transportation fuels is an area of focus of many island energy initiatives, this report focuses primarily on issues of RET deployment in the power sector and for water heating.

[3] http://www.irena.org/DocumentDownloads/events/Workshop_Accelerated_Renewable_Energy_Deployment/Pacific_Activities_071211_final.pdf

[4] http://www.irena.org/DocumentDownloads/PacificLeadersMeeting/Pacific_communiqu%C3%A9.pdf Accessed April 20, 2012.

Even with a favorable return on investment, financing can be difficult to obtain due to geographic isolation, small populations, relatively small project sizes, and low income economies. Financing often depends on the creditworthiness of project developers and utility counterparties. Little financing has been available outside of development banks and the donor community, and to date there has not been a regional approach to financing and deployment. Potential benefits of greater financing coordination are discussed in the concluding sections of this report.

Many RET systems have performed poorly or failed in PIC settings due to lack of local experience and inadequate maintenance. Proper installation and maintenance is critical to keeping RETs operational in the tropical PIC climates, as potential typhoons, high humidity, extreme heat, and corrosive salt air will have an impact on the equipment and will be detrimental to performance and life if not properly accounted for. While maintenance concerns present a challenge when introducing new technologies to an island setting, they also present an opportunity for technical innovation and workforce training and development.

Social acceptance can also be an issue in the case of wind turbines or large PV farms being located in view sheds, on previously undisturbed areas, or near culturally significant sites. Community outreach and involvement early in RET development planning is essential for communicating potential impacts and benefits as well as understanding and mitigating concerns and obtaining local buy-in.

In those islands that have made significant progress toward greater contributions of renewable energy, for example Hawaii and the U.S. Virgin Islands, several lessons emerge that are relevant to Pacific basin efforts, including:

- The importance of a power systems approach, integrating new sources of renewable energy along with end-use efficiency and grid modernization
- The importance of involving diverse stakeholders in the planning of energy system roadmaps
- Acknowledging the human dimensions of energy system transformation, for example the training requirements necessary to ensure ongoing operations and maintenance of RET projects
- The key role of high quality renewable energy resource assessments
- The key role of project development support.

Effective coordination at the institutional level is also critical to connect these diverse areas of planning. The alignment of national roadmaps, policies, and programs to implement the policies, is needed to achieve meaningful levels of RET deployment in PICs. A number of energy roadmapping activities have been undertaken in PICs, involving a wide range of stakeholders and generating momentum toward unified goals. Roadmap goals are most effective when supported by legislation and regulations to ensure the intent of the policies can be carried out. In most cases, assistance or training may be needed from regional entities or other experts to increase local capacity to develop the necessary regulatory framework and programs to enact and implement the policy initiatives. As PICs set goals for conventional energy use reduction and renewable energy production, it is increasingly important that supporting energy roadmaps are carefully crafted, implemented, and evaluated. This report focuses on specific considerations to support these efforts at a national and regional level.

2 Considerations for Renewable Energy Technologies in Island Settings

While RETs may carry many significant advantages over conventional fossil energy sources in island settings, attention should be given to the unique strengths and challenges of candidate technologies and to the conditions that may privilege one technology over another. Figure 1 provides a figurative illustration of some of these considerations.

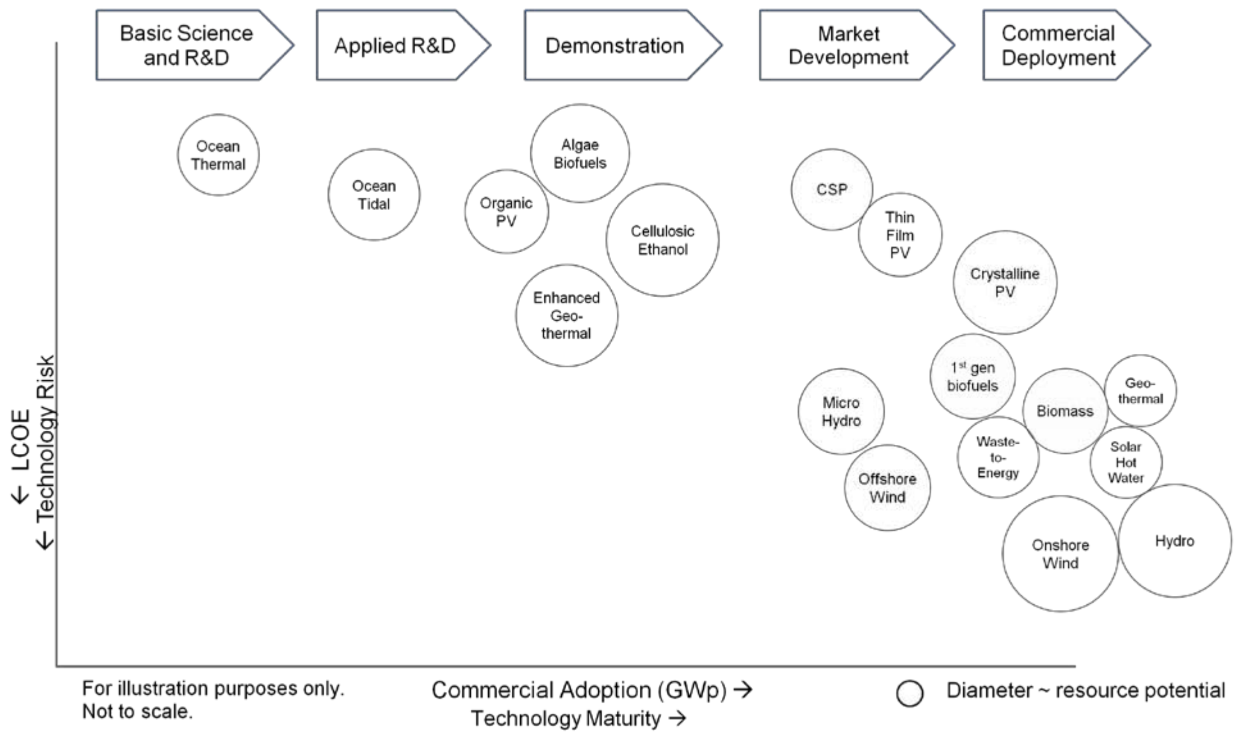

Figure 1. Illustrative schematic of technology cost and risk plotted with commercial maturity

Source: NREL

While there are a wide range of RETs available for consideration, implementation of commercially available technologies helps to ensure performance in island settings for a variety of reasons: they are readily available, typically include a warranty, and are generally well understood due to their track record of performance. To help keep this in perspective, Figure 1 illustrates relative technology risk, levelized cost of energy (LCOE), and commercial readiness of various RETs from basic research to commercial maturity. Generally speaking, technology maturity correlates with LCOE and technology risk. The circles in this figure depict the estimated commercial maturity, as of 2012, of a range of technology types; the diameter of each circle represents an estimate of global resource potential in broad technology categories. These estimates are for illustrative purposes only and are not specific to islands. Resource potentials and technology costs will vary significantly between different island settings where some resources may be more abundant or entirely absent. As shown in the figure, globally, hydropower is the most mature RET and provides the most baseload power, but opportunities for large-scale hydro power generation are often limited on islands.[5] The opportunities for wind, solar PV, solar water heating

[5] There are exceptions to this rule; for example, Fiji and Samoa produce significant percentages of their power from hydro.

(SWH), waste to energy (WTE), and biomass power production are much greater, and these are commercially available and proven technologies that can be financed in today's markets. Geothermal power, while also a mature technology providing low-cost electricity, requires substantial investment for exploration and development. The opportunities for biofuels and biomass energy vary widely between islands and typically require substantial investment in feedstock supply, conversion, and distribution infrastructure.

Prior to implementation of large-scale RETs, the available resource for a given PIC or area must be understood. Resource assessment strategies include meso-scale modeling and detailed site-specific data measurement programs. While some high-level worldwide wind and solar radiation data exists through organizations such as NASA, these datasets must be used with care due to their relatively low resolution, and local resource assessments at high resolution are necessary to properly develop utility-scale RET systems. Better understanding allows developers to reduce development risk and lower cost of capital.

No single renewable power technology or efficiency measure is likely to eliminate an island's dependence on conventional power systems and fossil fuels. Efficiency, conservation, and alternative energy sources should be developed in an integrated effort. In practice, an effective strategy involves comprehensive analysis of the portfolio of renewables and efficiency (supply-side and demand-side) that will provide the greatest reduction in fossil fuel consumption at the lowest life cycle cost. When evaluating renewable energy generation technology options, considerations include available energy resources, potential impacts of a technology or mix of technologies on the grid (when grid connected), life cycle costs, technology maturity, ongoing maintenance requirements and local expertise, and social and environmental considerations. Consideration should also be given to the micro-economic impacts of various applications and approaches. Large-scale grid-connected systems may have the greatest impact on overall fuel consumption, but small-scale systems directly serving homes, commercial buildings, or even unique isolated loads may have a greater impact on individual utility bills.

Of the technologies identified in Figure 1, SWH, solar PV, biomass, WTE, micro-scale hydro, and wind may be of particular interest to PIC stakeholders. The following sections briefly discuss each in turn, although additional information on the other technology options are available and may be considered in longer-range energy planning activities.

Solar Water Heating

Solar thermal technologies, also known as solar hot water, are typically low to medium cost and are easy to install, operate, and maintain. SWH is a well developed technology that already enjoys reasonably broad deployment in many locales. These systems can typically provide all of the hot water needs for residences, although hot water may not be seen as a need and may not currently be installed for some homes in tropical climates. Solar thermal technologies could also be considered for hotels, hospitals, apartment buildings, and laundromats where high hot water demands offset the capital costs of installing solar thermal panels. Larger solar hot water systems also allow the pre-treatment of water or the design of a closed-loop system that can partially address issues with water hardness.

Panels should be installed where there is full exposure to the sun without shading from buildings or vegetation, and according to local building regulations, including plumbing and access codes. High wind events are a concern for solar thermal survivability, flying debris damage and panels being blown off of rooftops, for example. Panels installed flat against the roof surface are more likely to withstand typhoon winds than those installed at an angle, although they may suffer from a loss of operating efficiency. Older evacuated tube collectors can often be observed mounted at an angle on rooftops in many island applications, having survived for many seasons.

The price of solar thermal systems has declined significantly over the past few years even while efficiency has increased. Based on high electricity costs in island communities, solar hot water systems provide an opportunity for energy and cost savings in both commercial and residential applications. Where larger industries exist and hot water consumption is high (e.g., hotels or manufacturing plants), solar hot water is a low- to medium-cost application with reasonable investment payback and relatively low technology risk. Although not likely to provide all hot water needs, solar thermal can offset electricity use for water heating by providing a portion of the hot water or pre-heating the water before it is heated electrically.

Figure 2. A Virgin Islands Energy Office intern inspecting a rooftop solar collector—St. Croix, U.S.
PIX19339

Compared to some other technologies, workforce training requirements of SWH are relatively low, as the technology relates to existing professions of plumbing and roofing.

Solar Photovoltaic

Solar PV directly generates electrical power and can be interconnected to the electrical distribution network. Solar power then acts as a direct offset to diesel power generation. Similar to wind power, the deployment of PV does not reduce the total installed capacity of diesel technology and, depending on detailed solar assessments, may not reduce the spinning reserve (unused and available capacity) requirements of diesel operation. It does lead to reduced fuel consumption and thus reduced expenditures for fuel on the islands.

Figure 3. 10 kW PV system installed on St. Thomas, U.S. Virgin Islands
PIX 19568

Most PV systems installed in island communities are in fixed-orientation configurations. For large electric utility or industrial applications, hundreds of solar arrays are interconnected to form a large utility-scale PV system. These systems are generally fixed in a single position. Arrays that rotate to track the sun are also available, but these may increase initial costs and ongoing maintenance requirements and may also increase the potential for damage from typhoons. Although typically mounted at an angle to maximize sun exposure, arrays can be mounted flat against the roof surface in climates susceptible to high wind events with a relatively small reduction in power produced.

Smaller solar PV systems can also be used to provide electricity to specific buildings or businesses. In the case of smaller installations, renewable technologies, including PV, are installed in what is typically called a "behind-the-meter" or "net-metering" application. In these cases, PV systems are installed on the customer side of the electrical meter and the energy generated is used by the consumer. Depending on local government and utility policies, excess electricity may be sold back to the utility at a rate defined under a net-metering regulation. PV can also be used in off-grid power applications such as solar electric street lighting, water pumping, and even community power systems.

Although not typically highlighted as much as with wind technologies, the power variability in large-scale PV installations can be significant due to the reduction in voltage when clouds pass between the sun and the PV array. If large PV systems are to be considered, for example, greater than 10% of the maximum daily load of a given distribution feeder, grid flow, and power balancing studies should be completed as part of the development process.

Wind

Wind resources on many Pacific islands are promising, yet wind power in an island setting requires particular attention to planning and design. Infrastructure for the development of large-scale wind deployment on many islands may pose a significant challenge. Availability and quality of roads, electrical transmission grids, and shipping infrastructure are all important factors that may vary widely between different island settings and may require some level of upgrade if large wind turbines are to be installed. Another limiting factor is the availability of a heavy lift crane to support turbine installation. Thorough assessments of harbor, heavy lift, and transport capabilities can help to determine specific weight thresholds, defining an upper limit for turbine size for each island. In all cases these issues reflect on project economics but do not significantly impact technical viability. Additionally, an environmental impact assessment can determine the potential impacts to avian species of a specific wind project.

Figure 4. Hawaii Renewable Development, owned by HRD LLC and located at Upolu Point near the northern tip of the Big Island. The project utilizes 16 Vestas V-47 660-kW turbines spread over approximately 250 acres.

PIX 14703

Typhoons pose an important risk in the use of wind technologies in island environments. All larger wind turbines (above approximately 30 kW in size) are designed to stop operating in high wind conditions, meaning that in all except the most extreme cases, storm-related damage is going to focus on that caused by airborne debris, typically to the turbine blades. Another potential issue is wind loading on the turbine structure exceeding the tower or foundation design loads. This is controllable, but engineering and design changes to mitigate the risks may increase capital costs.

Siting wind turbines in areas where extreme weather events are common requires careful assessment of technology options. Every large wind turbine is designed around an international standard for wind intensity provided in a class rating. The class rating also impacts the size of the wind turbine rotor, which has an impact on the resulting energy generation from the turbine. When selecting specific equipment or a wind development partner, turbine survival wind speed, as well as typhoon experience, should be key considerations.

At least two manufacturers offer a typhoon-rated wind turbine; however, it is not clear if this includes up to Class V typhoons. Recent analysis suggests that wind turbines are better able to withstand the force of typhoons and hurricanes if the rotors are pointed into the wind.[6] A major turbine manufacturer, Vestas, is currently marketing a turbine that includes a back-up generator to keep the turbines pointed into the wind in the event of a failure of the grid.[7] Additionally, Vergnet makes 275-kW turbine that is designed to be lowered during potential typhoons and extremely high wind events, and the company is production-testing a larger turbine whose rotor can be removed.[8] In most cases, and particularly when project insurance is desirable, a risk assessment is needed to determine the appropriateness of installing wind turbines in any typhoon-prone environment.

Although there has not been much extreme weather experience with large turbines in Pacific islands, a number of turbine installations in the Caribbean have been operating and have not reported major issues. Caribbean systems include a small system of four turbines installed at Guantanamo Bay on the eastern end of Cuba and a larger wind farm in Manchester, Jamaica (38.7 MW comprised of twenty-three 900-kW turbines and nine 2-MW turbines), both in areas prone to hurricane (typhoon) activity.

Insuring wind systems against extreme weather is also a pertinent concern, as pricing for such insurance may vary widely based on the turbine and the risk of extreme weather. Historically, insurance companies have not been willing to provide insurance for turbines in Class V typhoon areas, but with the development of turbines rated for typhoon environments, it may now be possible to do so. In a number of cases the turbines are also self-insured by government entities. In any case, one of the first steps in the development of potential projects will be to contact wind turbine manufacturers, either informally or through a competitive process, to better determine product availability and typhoon risks.

Although almost all wind turbines being installed today sit on top of a tower with an axis of rotation parallel to the ground, various manufacturers also produce vertical axis wind turbines (VAWTs). VAWTs can be preferable in some contexts because they do not sit on tall towers threatened by typhoons and they incur less visual disturbance. However, these turbines typically have a smaller rated output, between 5 kW and 50 kW, and because they sit low to the ground do not generally have good performance given the lower wind speeds found at lower blade heights. Because the turbines are typically installed close to the ground, they may be susceptible to damage from flying debris during high

[6] GIZ. "Caribbean Wind Energy Overview." 2011. http://www.carilec.com/members2/uploads/RE2011_Presentations/OrchidRoomSessions/13b_BJargstorf_TheCaribbeanWindEneergyInitiative.pdf. Accessed March 14, 2012.
[7] Vestas in the Caribbean. Presentation. 2011 CARILEC Renewable Energy Forum. Saint Thomas, September 2011.
[8] Vergnet GEV MP C Tiltable Wind Turbine. http://www.vergnet.com/en/gev-mpc.php Accessed March 19, 2012.

wind events such as typhoons. Although they are not currently candidates for large-scale power generation, in some cases, VAWTs may make sense for remote loads or in specific net-metering applications. As of the third quarter of 2011 (Q3 2011) no conclusive studies have looked at the avian impact of VAWTs, and few of these turbines have been certified to either U.S. or international standards. Care should be taken in selecting units for any application.

Biomass

Biomass is generally defined as any organic feedstock available on a recurring basis. Typical biomass resources include wood and wood waste, landfill gas, agricultural and crop residues, used vegetable oil, human solid waste, and animal manures. In an island setting, biomass resources can be used to produce fuel for cooking, power, or transportation. Biomass also allows baseload power generation, avoiding the issues with intermittent power provided by wind and solar. In many cases biomass can be used in existing power generation equipment.

Challenges for using biomass for power generation or for biofuels on islands include scale of feedstock availability, lack of information about biomass yield potential, and concerns over use of land. In Hawaii, significant variability in soil and precipitation conditions complicates crop selection, which in turn complicates the siting and "right-sizing" of processing and distribution infrastructure. Use of municipal solid waste (MSW) to create biogas for cooking or electricity generation requires a consistent, reliable volume and composition of waste. The amount of moisture in the waste will determine the appropriate technology for conversion to energy.

Figure 5. Biomass gasifier that uses residue from the nearby sugarcane mill—Maui, Hawaii

PIX 05237

Biofuels, particularly biodiesel, can be used as an energy source in transportation, power generation, and thermal boilers with minor equipment modifications. The Hawaiian Electric Company has successfully tested the use of 100% biodiesel to fire a 90-MW steam turbine generator at 100% capacity.[9] Development of agricultural crops for biofuels such as jatropha can be difficult given limited land availability in PICs, and use of existing resources may compete with food sources. Building upon previous studies of their irrigation systems, and with NREL support, Hawaii is considering carrying out multi-criteria studies of water and land use in support of bioenergy scale-up in both the fuels and stationary generation sectors.

[9] Hawaiian Electric Company. "HECO Successfully Tests 100% Biofuel in Oil-Fired, Steam Electricity Generator at Kahe Power Plant." http://www.heco.com/portal/site/heco/menuitem.508576f78baa14340b4c0610c510b1ca/?vgnextoid=9fbfb7ba04ecd210VgnVCM1000005c011bacRCRD&vgnextfmt=default&cpsextcurrchannel=1. Accessed March 14, 2012.

Waste to Energy

Addressing municipal solid waste (MSW) is an issue in all island communities as land is typically scarce and waste cannot be easily disposed of in an environmentally sustainable manner. Many islands have found waste management to be a significant challenge—for example, various U.S. Virgin Islands (USVI) landfills are currently non-compliant with U.S. Environmental Protection Agency regulations, and the landfill on the island of Guam has been under receivership since 2008.[10]

WTE represents an approach to addressing islands' waste and energy needs. WTE technologies consist of various methods for extracting energy from waste materials. These methods include thermochemical and biological methods. Figure 6 illustrates the various pathways, most of which are still in early technology development stages. With the exception of landfill gas, the only WTE technology that is currently commercially available in the United States uses MSW feedstock for combustion. Other processes hold significant potential for utilizing MSW feedstock but must overcome various technical or procedural challenges before they are commercially viable. The primary challenge facing these technologies is the heterogeneous nature of MSW, which creates a widely varying chemical constituency of the energy products generated from these processes. This variance affects the ability to extract energy efficiently.

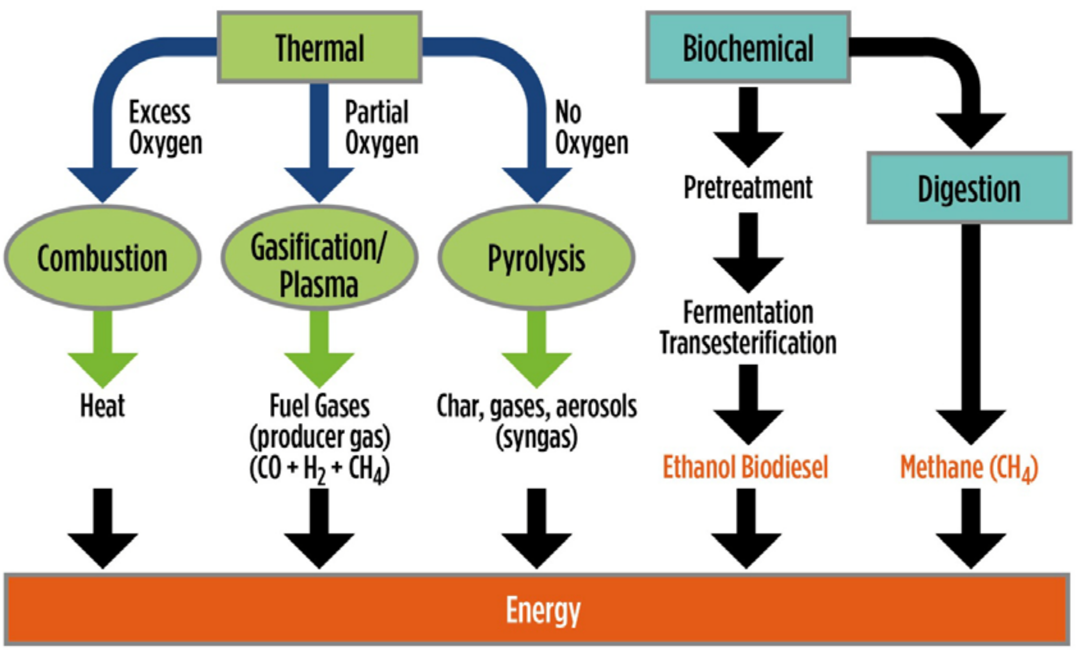

Figure 6. WTE conversion pathways

Advantages of producing energy from waste include a reduction in the volume of waste to be landfilled and reduction of greenhouse gas (e.g., methane and carbon dioxide) emissions. As discussed in Section 2.4, other waste products, such as green waste, wastewater treatment plant sludge, agricultural residues, and animal wastes, can also be used as feedstocks to produce thermal or electric energy.

[10] Guam Solid Waste Receivership Information Center. "Court Order." http://www.guamsolidwastereceiver.org/courtorder.html. Accessed January 2012.

One concern raised about WTE is associated air emissions, specifically for combustion technologies. This is a valid concern that should be addressed by the developers and designers of any proposed WTE system since significant improvements in these technologies have been realized in recent years. Current emissions standards from these facilities are presented in Figure 7, which includes the average of 87 U.S. WTE facilities as well as an average of the top contenders for a recent industry award for low emissions.[11,12]

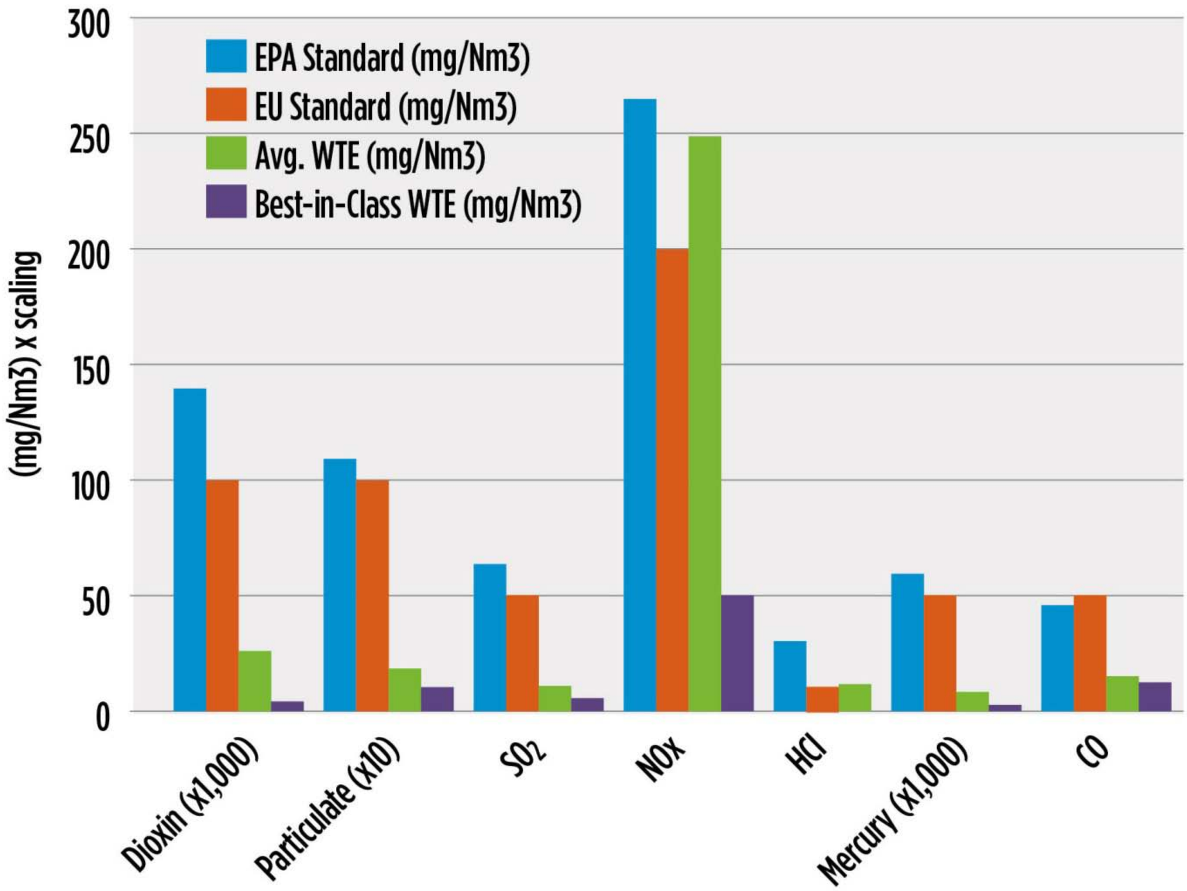

Figure 7. U.S. WTE emissions profiles

One example of a successful WTE plan is Hawaii's HPOWER facility near Honolulu, shown in Figure 8. This facility processes up to 2,160 tons of waste per day and generates up to 57 MW of energy for the island. The system recovers over 20,000 tons of metal a year. The facility is currently being expanded to be capable of processing over 3,000 tons of waste per day.[13]

[11] Psomopoulos, C.S.; Bourka, A.; Themelis, N.J. "Waste-to-Energy: A Review of the Status and Benefits in the USA." *Waste Management*; Vol. 29, January 2009; pp. 1718–1724.
[12] Themelis, N.J. "Thermal Treatment Review." *Waste Management World*; July–August 2007; pp. 37–45.
[13] Covanta Energy. "Energy-from-Waste Facility." http://www.covantaenergy.com/covanta-us-home/facilities/facility-by-location/honolulu.aspx. Accessed March 14, 2012.

Figure 8. HPOWER waste-to-energy plant operated by Covanta Honolulu

Source: Adam Warren, NREL

Micro-Scale Hydropower

In many locations hydropower has significant potential to provide an important contribution to the future energy infrastructure in both isolated and grid-connected applications. Large streams or small rivers can often provide power for a village, while larger rivers can provide utility-scale generation. Hydropower can also be a steady source of power if the source provides only minimal seasonal variation or if water storage is incorporated. It can be used to complement thermal generation and other more variable renewable power sources, such as solar and wind. Seasonal variability and annual drought cycles are a concern with all hydro generation, as is the potential for long-term climate trends brought on by global climate change.

In locations with good hydro resources, hydropower is typically one of the lowest cost and most reliable forms of power generation available. With proper maintenance and operation, a facility can operate for many years. Operating hydro facilities over 100 years old are not uncommon. Due to the significant civil engineering needs for even smaller micro-hydro facilities, the capital costs of hydro projects are typically relatively high, although their average lifetimes and capacity factors results in a relatively low LCOE.

Hydropower projects generate power according to the volume of water and the force that this water exerts on a power turbine. In a typical hydro system, water is diverted from a stream into a pipeline where it is directed downhill and through a turbine that is connected to a generator. Although simplistic, two simple terms provide much information about a potential hydro project: flow and head. The total amount of water that can run through the power plant over a period of time is called the flow. The vertical drop of that water, which in turn creates pressure at the bottom end of the pipeline, is called the head. The pressurized water emerging from the end of the pipe creates the force that drives the turbine. More flow or more head produces more electricity and basically determines the water power available to be harnessed. Electrical power output will always be slightly less than water power input due to turbine and system inefficiencies.

Island communities typically have small streams and rivers that, combined with mountainous topography, can provide very good locations for small hydro projects. Although hydropower systems can range from several kilowatts all the way up to thousands of megawatts, for the sake of this discussion only the smaller projects are discussed. Although there are no universally defined classifications for hydro projects, a micro hydropower system typically produces less than 1,000 kW, although systems less than 100 kW are commonly used to provide power to rural communities in the developing world. Typical for small community or industrial uses, these power systems are relatively simple, using basic civil works and turbine technology. In most cases, a small dam is constructed across the river, making a small reservoir to control water flow into the hydro system. Several levels of screening are implemented to keep debris from entering the pipe that brings water to the hydro turbine. The turbine generates power from the water; an electronic controller ensures good quality power is provided to the community or an island transmission system. Larger power systems, ranging up to 20 MW are classified as mini- to small-scale hydro projects but generally share the same design concepts.

If topography allows, two general types of hydro projects are considered common, regardless of size: diversion and impoundment. In diversion systems, water is diverted from the main flow, sometimes using a small dam, and this water is run through power turbines and then returns to the watercourse. Any water not used for power generation is allowed to continue its flow, which results in the term "run-of-river" hydro systems. Impoundment systems capture the water flow from a whole watercourse behind a large dam, typically flooding a large geographic area. Water can be released, running through the generator or over a spillway, to control power output or water level behind the reservoir. Power is generated by taking water from behind the dam and running it through generation turbines. Since there is a dam, power generation is less dependent on the seasonal nature of the water resource, although this does play a dominant role when power is available. Impoundment dams are typically installed in areas where natural catchment zones exist, such as large canyons or natural lakes, to limit the need for civil infrastructure. With the addition of pumping infrastructure, an impoundment facility can also be used for pumped storage, where water is pumped up to the impoundment during times of low power need only to be released during time of high energy need. In places where the value of on-peak or off-peak power is large, companies have implemented purely pumped storage facilities, where no natural water flow is used to generate power.

3 Energy System Integration in Island Nations

Energy is a cornerstone of the economics of many island nations; however, electrical energy use is only one portion of the energy system. Most island communities utilize petroleum fuels for a wide range of uses, including electricity generation and land- and water-based transportation. While this report focuses mainly on considerations for renewable energy deployment in the electric sector, the full range of end uses are important for energy system planning. Furthermore, in all areas of energy end use, efficiency and forecasting of demand are important considerations for integrated planning. This section considers some of the key issues around a systematic transition to greater reliance on renewable technology sources.

Integrated Energy Planning

As with most electricity system planning, energy efficiency in island grids is an important component of total system analysis. In both electrical end use and transportation end use, improved efficiency often represents a low-cost petroleum reduction strategy. In electricity use, climate-appropriate building design can reduce the need for cooling and the proper selection of major appliances (e.g., water heating and air conditioners) can greatly reduce baseload energy requirements.

Comprehensive analysis can be carried out to assess, rank, and prioritize energy efficiency and renewable energy strategies. The supply-curve-type analysis is a signature effort that can help to structure long-range, least-cost planning processes in island settings. When this sort of analysis is carried out, as it has been in the USVI, the role of energy efficiency as a low-cost, high-impact pathway to reduced petroleum dependence is evident (see Figure 9).

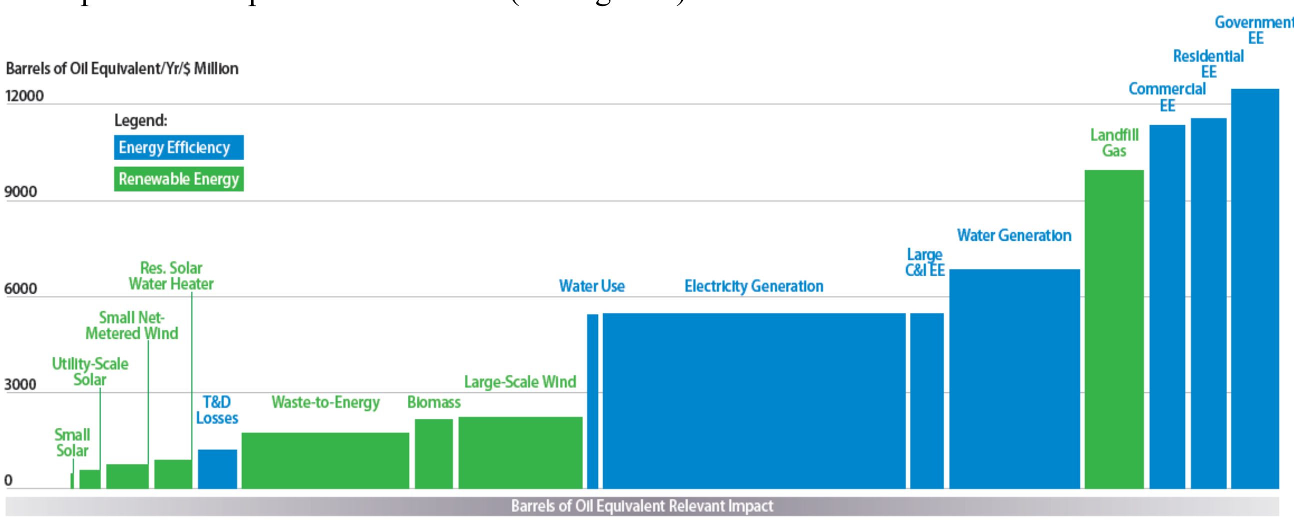

Figure 9. Estimated cost effectiveness and impact of the various energy efficiency and renewable energy strategies considered by the U.S. Virgin Islands road map[14]

Note: The height of each bar represents an estimate of the island-specific cost effectiveness of a given investment. The width represents energy savings assumed in the analysis. All scenarios are aggressive.

[14] Lantz, E.; Olis, D.; Warren, A. *U.S. Virgin Islands Energy Road Map: Analysis*. TP-6A20-52360. Golden, CO: National Renewable Energy Laboratory, 2011; 121 pp.

Regarding transportation, the expanded development of electric and hybrid electric vehicles, including cars, trucks, all terrain vehicles, motorcycles, and even scooters, may allow island nations to reduce dependence on imported fossil fuels. Although many of these vehicles may have reduced social acceptance in locations with large road networks, the constrained markets of many islands make these technologies much more appropriate. Policies to incentivize improvements in average vehicle fleet efficiency have been investigated on many islands, including Hawaii, and while fleet turnover is typically slow, such policy frameworks hold significant promise to reduce overall petroleum dependency. The petroleum impact of electrification of light-duty vehicles depends primarily upon changes in the mix of electricity generation since switching from a fossil fuel engine to one that is powered by electrons from a diesel generator does little to reduce overall petroleum dependence. But vehicle electrification may facilitate an easier transition from a transportation sector fueled by imported sources to one that is dependent on locally produced clean energy sources. The adoption of biofuels also supports similar goals but, in the case of imported ethanol or bio-diesel, may simply result in replacing one imported energy source with another. Significant land and water use issues may accompany large-scale biofuels production on constrained islands, an area of competition that represents another prime subject for integrated energy planning.

Grid Integration of Renewable Power Technology

When incorporating renewable-based technologies into isolated or islanded power supply systems, the amount of energy that will be obtained from the renewable sources will strongly influence the technical layout, control requirements, performance, and economics of the system. When the overall contribution of energy is low and dispersed across the electrical distribution system the grid impacts are typically quite minor. If renewables are concentrated in one location, such as a larger wind or solar power system, consideration of power flow between these devices, the conventional generators, and loads need to be considered, especially over short time intervals. As contributions of renewable technologies rise, the control of voltage and frequency becomes more complex. Many systems have been deployed that incorporate higher levels of renewable contribution, and a primary lesson of these efforts is that the power system must be tailored to fit the design parameters dictated by the existing power infrastructure, available renewable resources, and geographic layout of the location.

As penetrations increase, system balancing technologies are typically required. While cycling of diesel generators is the prevalent solution on islands, a range of other systems have been deployed, including, for example, controllable hydro turbines in Kodiak, Alaska; battery storage in Hawaii; and flywheels incorporated into the power systems of Coral Bay, Australia and Ross Island, Antarctica. Each of these options provides balancing services that allow higher contributions of renewable energy to be incorporated into conventional islanded power systems. The wind and diesel power system operating at the airport and industrial complex in St. Paul, Alaska, uses thermal water storage technologies, allowing the diesel engines to shut off when the wind turbine is producing more electrical energy than is needed, with any excess used for thermal heating.

Other demand-side systems can also offer important balancing services for intermittent energy. The growing integration of smart grid communication technologies into industrial, commercial, and residential loads may increasingly allow grid operators to rely upon demand response to assist in grid balancing under high penetrations of RETs. For example, with appropriate technology and system modifications, flexible loads such as hot water heaters, industrial chillers, or agricultural water pumps can be turned on or off to help shape the overall load curve in response to variable renewable energy production.

Transmission integration challenges also arise if load centers are distant from high quality renewable resources. For example, on Hawaii, significant wind resources exist on the lightly populated islands of Lanai and Molokai. Bringing this power to population centers would require an inter-island cable project. Such undersea cabling projects are also at an early stage of consideration in the USVI. While the capital cost of underwater cable is significant, continued cost reductions in high-voltage DC technology may eventually benefit island grids. Besides the cost of the cable itself, the depth, distance, and infrastructure characteristics of the project will also play a significant role in determining the final cost of an inter-island connection.

Pursuing an integrated view of the various generation, grid modification, and system balancing options is an important task. Appropriate selection, design, and control of renewable and conventional thermal generation, as well as measures to incorporate energy storage and dynamic load control, can greatly support higher contributions of renewable technologies.

Denham, Australia

The Denham wind–diesel power station is operated by Western Power and is located on the western coast of Australia, north of the regional capital of Perth. The electrically isolated power system has a maximum demand of 1,200 kW, which is supplied by 690 kW of wind generation from four 230-kW Enercon E-30 wind turbines, four diesel engines with a total rating of 1,720 kW, and two low-load diesels, which can operate down to about 10% of rated power. The power system was installed by PowerCorp of Australia and is controlled from a highly automated control center located in the powerhouse. The power system has the capability to operate in a fully automated mode with minimal technical oversight. The system control allows all of the standard diesels to be shut off, resulting in an average wind contribution of 50%. The power system has been operating since 1998, supplying utility-quality power and saving approximately 175,000 liters (46,230 gallons) of fuel per year (PowerCorp. “Wind Diesel Power Systems.” http://www.pcorp.com.au. Accessed January 1, 2012).

4 Human Dimensions of Deployment

Deployment of RETs and energy efficiency is not solely a technical matter. Institutional, cultural, economic, and policy issues all play a significant role in the success of any project. The U.S. Department of Energy (DOE) and the National Renewable Energy Laboratory (NREL) have accumulated significant experience in these "human" dimensions of energy deployment. Lessons learned in these experiences are vital and can support a coherent approach to supporting communities in a transition to higher levels of renewable energy.

Transformational change in anything, including the energy system and energy use, requires close collaboration of local stakeholders. Stakeholders in this effort include the utility, local government, schools and educational institutions, local businesses, fuel suppliers, finance partners, and residents of the island communities. Developing a common vision is critical to determining a path forward and creating actionable goals. Collaboration ensures that all stakeholders have an opportunity to share their motivations, concerns, and ideas for changing the island's approach to energy generation and consumption. For example, the Hawaii Clean Energy Initiative (HCEI) has established topical working groups to provide broad representation as well as long-term vision and continuity to planning efforts. Implementing significant changes in energy systems and energy use and realizing the benefits of those changes takes time. This requires a collective vision with measureable goals and a stepped timeline for implementation and coordinated government policy, planning, and budgetary support.

Impressions about renewable energy systems and their performance will play a role in local acceptance of development plans. Involving island community stakeholders throughout the planning process will help the understanding of the full process development scope and timeline. A range of renewable technologies have been installed by various donors on islands in the Pacific, and in many cases have failed due to improper selection of technology for a particular application, faulty installation of the system or components, or inadequate maintenance. This can leave the impression that a particular technology does not work or does not work on the Pacific Islands.

Figure 10. Team members from the University of Puerto Rico assemble their house at the second Solar Decathlon, an international collegiate competition to design and build efficient solar-powered houses

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Workforce Development

Although in many cases expertise in implementing and maintaining renewable energy systems must come from off-island, this presents an opportunity to develop training programs to create jobs for local installers and maintenance technicians. Where conditions allow, workforce development training is a significant boost to the local economy. These training programs are often partnerships involving the trades (e.g., electricians, plumbers, and HVAC installers), local colleges or trade schools, regional training organizations, and project developers. In Hawaii, for example, the consortium of organizations that manages training initiatives for the RET sector includes the Hawaii Workforce Investment Board; the Hawaii Department of Business, Economic Development, and Tourism; the University of Hawaii Community Colleges; the Hawaii Electric Company; and a variety of unions and builders associations.

Workforce training requirements for wind and solar PV energy can be significant but are not out of reach for most PICs. Increasingly, training programs from Europe, the United States, Australia, and other countries are available through online distance learning or can be offered through local community, vocational, or university systems. Some levels of technical service, such as large wind turbine maintenance, require multi-year activities based at a manufacturer, in community colleges, or other equivalent institutions and thus would not likely be supported by an individual island educational institution. Skills for large-scale renewable installation will also likely fall to off-island professionals, though with the right incentives, such organizations may take advantage of local commercial and human resources to the extent possible. In most cases, large installers of renewable technologies provide a warranty service and maintenance contract that cover the first few years of system operation.

Inclusive Project Management

Through work with many island and non-island communities, NREL has developed a number of models for managing project design and implementation. These models are useful in helping communities new to change management understand the change process. For example, in the USVI, working groups were set up to address the various aspects of achieving their goal of a 60% reduction in fossil fuel usage by 2025. These working groups are contributing to the community energy planning process. This model is helping other island communities meet their energy goals. The general framework for inclusive, multi-stakeholder project design and implementation includes three iterative stages, plan, assess, and implement, as described below.

Plan

The planning phase includes bringing the right stakeholders together from across the community to create a shared vision. The goal of this phase is to create a benchmark vision that sustains efforts toward the community's energy transformation.

Assess

The assessment phase includes these steps:

- Determine an energy baseline
- Evaluate options
- Develop goals
- Prepare a plan
- Get feedback on the plan from a broad set of stakeholders.

The goals of this phase are to:

- Determine the community's energy baseline
- Establish specific, measurable, attainable, relevant, and time-bound goals for energy transformation
- Put the goals into a plan for action.

Implement

The implementation phase includes these steps:

- Develop, finance, and implement projects
- Create early successes
- Evaluate effectiveness and revise as needed.

The goals of this phase are to:

- Implement energy projects that can build community support for ongoing and future energy projects
- Measure the progress and effectiveness of the plan and its projects.

5 Strategies for International Cooperation, 2012 and Beyond

Sections 2–4 sketched out the state of energy transition and petroleum reduction efforts in island communities. Looking forward, the unique opportunities and challenges of this transition are of great interest to all PIC stakeholders. The Pacific Islands face some of the clearest incentives to embark on this transition. They are uniquely exposed to petroleum price and supply chain vulnerabilities, but they also face some of the starkest technical, institutional, and financial challenges in making this transition. Perhaps most importantly, most PICs face the challenges of geographic remoteness and economic isolation. It should be understood, however, that if organizations within PICs can develop the methodologies to address these issues, there are nations and organizations across the globe that are eagerly awaiting to implement the lessons learned. This provides a unique opportunity to PICs in that they may not only address the problems that they are facing locally but can export this knowledge, technology, and experience around the globe. Below, we discuss this challenge in more depth and then suggest potential pathways forward, with a focus on priority areas for PIC and IRENA stakeholders.

Scale Versus Customization

Global experience strongly suggests that economies of scale can dramatically reduce cost and risk of RET deployment, and yet achieving scale in PICs is difficult given the geographic dispersion of islands and the diversity of grid profiles and resource characteristics. In order to capture economies of scale (and reduce costs of very small installations), stakeholders face the challenge of articulating pathways to a regional finance and deployment strategy. Some of the broad features that promote and obstruct economies of scale are in Table 1.

Table 1. Barriers and Pathways to Scale

Unique Features (Barriers to Scale)	Common Features (Pathways to Scale)
Varying level of transmission and distribution capacity and quality	Common exposure to petroleum cost and volatility
Varying mix of distributed generation vs. utility generation	Abundant solar resource potential
Varying penetration of high-efficiency diesel generators	Growing experience with grid integration
Varying exposure to typhoons/extreme weather	Common interest from international aid and financial organizations
Varying grid operation standards (e.g., 50 Hz vs. 60 Hz operation)	Increasing inter-governmental collaboration
Varying resource profiles (esp. on- and off-shore wind, geothermal, biomass, and hydro)	
Varying load profiles (esp. tourism, hotels, industry)	
Varying levels of bankable resource assessment data	
Varying levels of workforce and institutional readiness	

Unique Features (Barriers to Scale)	Common Features (Pathways to Scale)
Varying legal treatment of independent power producers or other private project developers	
Varying credit availability and cost	

Here, we will not explore all of these barriers and pathways in depth. Some factors merit further discussion. As noted earlier, the quality of renewable resource assessment data varies widely across the region, which can dramatically impact the participation of renewable energy project developers and banks. Various grid-related factors that differ between island nations are also of particular importance, as they may frustrate efforts to reduce cost. If certain grid system specifications were widely shared across the Pacific basin—for example, system frequency, transmission line voltage, and distribution system phase and voltage—renewable energy interconnection standards might be harmonized, and bulk purchasing of equipment, training, and insurance might be feasible. As it stands, both 50 Hz and 60 Hz frequencies are present in the region, and transmission and distribution (T&D) system configurations vary widely.

Varying market and contractual treatment of independent power developers may frustrate efforts to reduce cost and speed deployment. Variance in power market structure and the legal characteristics of power purchase agreements across the Pacific basin may incur additional legal and financing costs to project developers and financiers.

Load profiles, which vary widely between island nations, also strongly influence the feasibility of various balancing options to accommodate high penetrations of variable renewable energy. Islands with significant industrial or commercial loads—for example, thermal chillers, water pumps, or dimmable ballast lighting—may be able to leverage these loads as a flexibility resource. While a degree of control system sophistication is necessary to introduce these demand-side resources into grid operation, even if upgrades are necessary, industrial and commercial demand response could represent a competitive option compared to cycling of diesel generators.

Potential Priority Action Areas for Pacific Island Assistance

The broad diversity of power market and grid characteristics will likely remain a barrier to cost reductions through shared learning and economies of scale. In the light of these barriers, and the unique technological and economic circumstances facing the Pacific Islands, we suggest the following as potential priority action areas to increase deployment of RETs on the Pacific Islands.

5.1.1 High Resolution Renewable Energy Resource Assessments and Cost/Benefit Analyses

While some data for locations in the Pacific seem to exist, there does not appear to be readily accessible and bankable renewable energy resource data available either for specific PICs or on a regional level. A detailed regional resource assessment would provide the data needed to better understand the level of various resource availability and locations and the amount of renewable power generation potential for those locations. This helps reduce the risk of project underperformance and costs associated with that risk.

To the extent possible, resource assessment work could be extended to include cost (and possibly benefit) analysis to better help countries in assessing the economic impact of RET investments. If IRENA were to perform or support additional resource assessments, it is recommended that such work build upon efforts being undertaken by other organizations such as the Pacific Islands Greenhouse Gas Abatement through Renewable Energy Project (PIGGAREP) to avoid overlapping efforts, support harmonization of assessment strategies to ensure consistency, and further develop a regionally harmonized approach.

5.1.2 Renewable Energy Electric Grid Integration Assistance

While many islands are setting ambitious goals to switch from primarily fossil fuels to renewable energy generation, there are a number of challenges previously described to implementing higher contribution variable power integration onto isolated grid systems. While this may not be an issue where very small systems are installed, a range of technical studies—including load flow, T&D modeling, and power balancing studies—may be needed to determine the full impact of renewable energy integration on specific feeders and the overall power system.

Although models and processes are being developed to allow the analysis of high contribution renewable power systems, these tools are somewhat limited in their capability and few organizations and international consulting companies have extensive experience in their use. Additionally, the expanded use of energy efficiency and active load control technologies will allow power entities managing isolated grids to provide better and lower cost power to all customers. The development and validation of design methodologies, new technologies specifically designed around isolated grids, and education of energy practitioners about the complications and savings of expanded RET deployment in isolated and island communities will be required if all of these islands are going to meet their stated national goals.

5.1.3 Coordination and Development of a Regional Financing Vehicle and Regional Technology Approach

As discussed above, financing efficiency measures and renewable energy deployment is a particular challenge for remote island nations. Isolation from mainland economies, relatively small populations and economies of their own, and the expense of implementing RET systems without economies of scale make return on investment difficult. Depending on renewable resource similarities for various locations, a regional technology deployment approach could be developed along with the financing vehicle.

One example might be a loan guarantee facility (or a revolving loan fund) tailored for island RET development. Different islands have varying abilities to issue bonds and other forms of public debt, as well as varying access to capital markets and development banks. For those with limited access to private equity and debt, a partnership between IRENA and other major regional development banks could fill the financing void and leverage private finance in project development.

Another option would be a form of efficacy insurance for island technologies. Many firms are happy to warranty their technology for mainstream deployment but are hesitant to warranty the same technology in distant island settings. In the absence of such warranties, project developers either assure technology performance directly or shift all of this risk to the customer. Neither case is optimal and so can lead to underinvestment. A public-private insurance facility to underwrite the performance of technologies could bridge this gap.

If such targeted finance vehicles could be developed for technology deployment and financing, a regional economy of scale may be created that could potentially reduce implementation costs, improve deployment strategies and penetration, and methodically reduce petroleum use on a regional basis. These activities could be coordinated with regional data collection and roadmapping to increase effectiveness.

5.1.4 Coordination Between Island Peer Groups

Not surprisingly, and as noted in Table 1, barriers to scale outnumber pathways to scale in Pacific Island RET deployment. In this light, and given the nature of these barriers, PIC stakeholders would benefit from regional research aimed at analyzing the resource, load, T&D, and workforce profiles of PICs in the aggregate. In other words, in parallel with efforts to produce high-quality, bankable resource assessments for individual PICs, efforts could be initiated to organize and aggregate grid data across the Pacific basin. To streamline this effort, this project would begin by determining the level of information that exists in regional entities, such as the PPA, ADB, and the Secretariat of the Pacific Community. The outcome of such a research project could be a whole-basin taxonomy of development characteristics that facilitates the “bundling” of multiple islands into attractive project financing efforts.

For example, a group of islands that share certain characteristics—active tourist industries, adequate T&D infrastructure, creditworthy off-takers, and relatively new diesel generator capacity—will represent a potential opportunity to “bundle” utility-scale RET development project finance. On the other hand, a group of islands with low per capita gross domestic product (GDP), limited utility off-take capacity, and limited T&D and generation infrastructure will represent a potential opportunity to bundle project finance for T&D and generator upgrades. Combining islands into these “peer categories” could facilitate brokerage of project development and could elevate project sizes sufficiently such that sophisticated project development and finance mechanisms could be deployed to reduce costs and improve project terms for island communities.

5.1.5 Partner with Existing Training Organizations to Enhance Programs and Delivery

Several organizations based in the Pacific provide RET training on a regular basis. The trainings vary from renewable energy basics to hands-on installation training for small systems. IRENA may consider partnering with these organizations (e.g., ADB, PPA, SPC, and the University of the South Pacific) to determine additional PIC training needs, support more detailed curricula development, and enhance delivery throughout the region. From a technical perspective, this will likely involve more detailed training in energy systems, grid integration, and maintenance. Training in the area of policy development, supporting regulation, and program implementation is also a clear need. Specific subtasks in the area might include inter- and intra-island peer working groups and high-quality virtual communities.

5.1.5.1 Inter-Island Peer Working Groups

Human capital development is essential for long-term success of petroleum reduction efforts. In concert with the peer group categorization articulated in Section 5.2.4, which is primarily a data-gathering and analysis effort, the taxonomy of island characteristics could support the formation of inter-island peer working groups. These working groups could be hosted through existing networks (e.g., PPA and Pacific Island Forum) in support of sharing knowledge and deepening collaboration between PIC leaders. These peer groups would serve several important purposes:

- Developing a common understanding of grid, resource, load, and institutional characteristics
- Generating appropriate training and educational resources for island peers that share grid characteristics
- Coordinating and harmonizing energy roadmap efforts at an inter-island level in support of economies of scale
- Presenting a unified body that can serve as the official point of contact for multi-island project developers and financiers.

5.1.5.2 High-Quality Virtual Communities

Also in support of long-term human capital development, and in light of the severe cost of in-person meetings, efforts could be made to establish high quality virtual community platforms. For example, facilitated education and training programs could be conducted for working groups and other PIC leaders, connected via broadband video conferences. The barriers to such a Pacific basin "Virtual Energy Academy" are numerous: access to broadband internet, video conference equipment, and staff and volunteers to ensure a vibrant schedule of events. Yet the alternative, expensive and time-consuming travel, is prohibitive except for occasional meetings.

5.1.6 Island Innovation Program

The special characteristics of many island settings—remoteness, severe weather, high humidity, extreme heat, and corrosive salt air—place unique technical and maintenance demands on RETs. Yet due to relative market size and ease of commercialization, allocation of resources for RET innovation migrates to technologies designed for mainland settings. These, and a variety of other market barriers, will continue to retard research and development investment in RETs for island settings. Additionally, demand-side barriers, namely the fragmentation of demand across multiple small islands, will further retard investment in innovation. Policy instruments and intergovernmental partnerships can help remedy these market imperfections. For example, public tenders from the U.S. military for a certain quantity of low-maintenance solar water heaters or wind-diesel hybrid plants could stimulate demand for island-appropriate RETs. This demand could then be leveraged to reduce the cost and risk to PIC customers. In addition to demand, maintaining a healthy supply of island-appropriate innovations is also an important consideration. Intergovernmental funding for targeted research, demonstration, and deployment, perhaps through a "Pacific Renewable Energy Technology Laboratory," would increase the pipeline of island RET innovations. While there is attention being paid to island-specific innovation in northern Europe (e.g., Gotland Island in Sweden and Samsø in Denmark), PIC innovation efforts are less advanced. While there are exceptions, notably Australia through its Clean Energy Innovation Centre, this area is a candidate for greater intergovernmental collaboration.

5.1.7 Project Development and Pre-Development Support

The development of RET projects is challenged by the relatively low level of understanding within the power sector and policymaking communities, both of which add risk to project development. For both power sector professionals and policymakers, an in-depth understanding of the RET project development process will be required if PICs hope to attract qualified project developers and financiers. The relatively small nature of most PIC markets also means that host organizations may need to go further in the development of projects than what would be typical for projects in countries with more developed and larger markets. These challenges may combine to make it difficult for PICs to execute successful RET projects at the most advantageous price, an issue that has been demonstrated by many unsuccessful request for proposals released by island and developing nations. Training and support before and during the pre-development and development process will greatly assist the execution of many RET projects and will serve to lower the risk (and cost) of subsequent projects.

6 Conclusions

Renewable technologies have the potential to greatly support the development of island nations across the Pacific basin and around the world. The expanded use of energy is one of the cornerstones of the modern world, and a move to a more locally sourced energy technology protects island nations from the vagaries of the international energy market. It protects nations from potential supply disruptions and exposure to commodity price fluctuations. Island nations will likely face significant impacts from climate change, whether due to sea level rise or intensification of storms.

While expanded reliance on RETs helps to mitigate climate change risks, the move to a power system based more on local energy technologies requires the development of knowledge, skills and operating procedures that may not be widespread in isolated island communities. Priority areas for facilitating greater utilization of RETs in island settings include:

- Utilizing a power systems approach that considers a variety of new sources of renewable energy along with end-use efficiency and grid modernization
- Involving diverse stakeholders in the planning of energy system roadmaps and roadmap implementation
- Acknowledging the human dimensions of energy system transformation, especially the training requirements necessary to ensure ongoing operations and maintenance of RET projects
- Conducting high quality renewable energy resource assessments
- Technical and financing support for RET project development.

As Pacific island countries and territories work towards reductions in fossil-fuel dependency, coordination of these priority areas will support overall success. Through regional collaborations to build human capacity and technical expertise, many of the issues that make it difficult to expand the use of renewable technologies can be addressed, bringing concrete, long-term benefits to Pacific island citizens.

Appendix A: Summary of Electricity Production and Oil Consumption for Select Pacific Island Countries

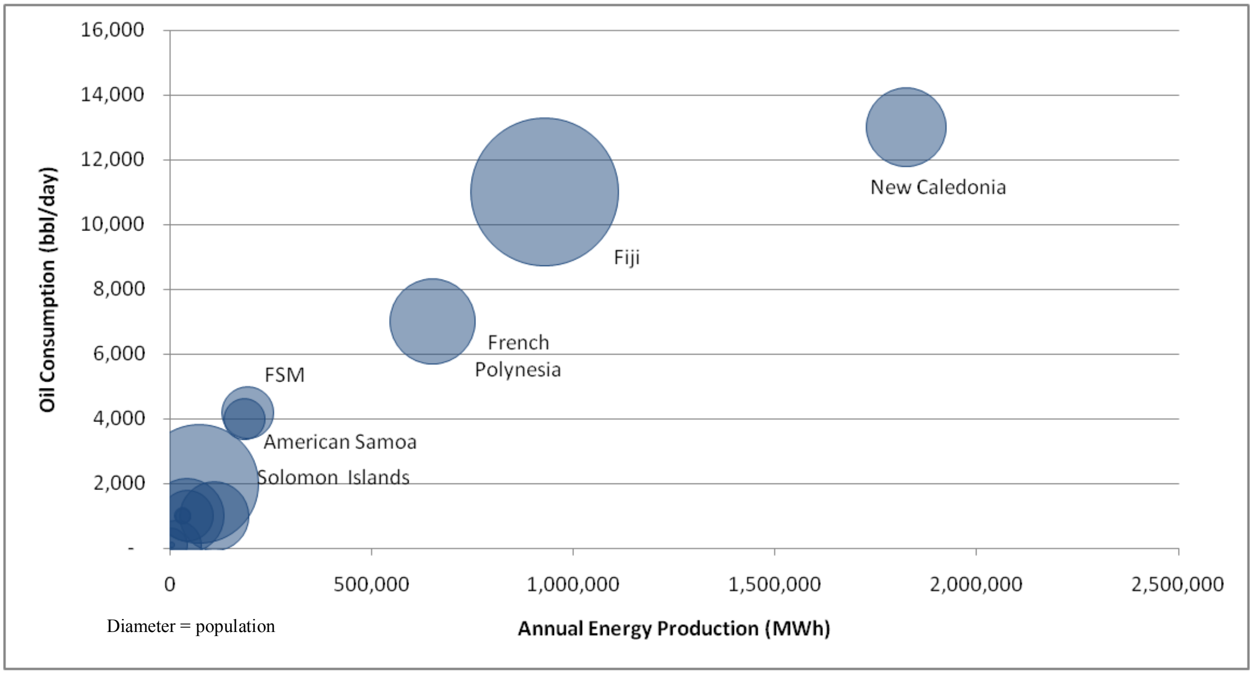

Figure A-1. Annual electricity production versus daily oil consumption for select PICs

Source: CIA Factbook 2011[15]

[15] CIA Factbook. Comparative electricity production data: https://www.cia.gov/library/publications/the-world-factbook/rankorder/2038rank.html; Comparative oil consumption data: https://www.cia.gov/library/publications/the-world-factbook/rankorder/2174rank.html. Accessed March 19, 2012.

Table A-1. Summary Energy Usage Statistics for Select Pacific Island Countries

Country	kWh Produced	Oil Consumption (bbl/day)	Population
New Caledonia	1,825,000,000	13,000	256,275
Fiji	928,000,000	11,000	883,125
French Polynesia	650,000,000	7,000	294,935
Micronesia, Federated States of	192,000,000	4,200	106,836
American Samoa	185,000,000	4,000	67,242
Samoa	109,000,000	1,000	193,161
Solomon Islands	71,000,000	2,000	571,890
Tonga	43,000,000	1,000	105,916
Vanuatu	42,000,000	1,000	224,564
Cook Islands	31,000,000	1,000	11,124
Nauru	31,000,000	1,000	9,322
Kiribati	14,000,000	100	100,743
Niue	3,000,000	100	1,311
Northern Mariana Islands	60,600	100	46,050
Total	**4,124,060,600**	**46,500**	**2,872,494**

Data source: CIA Factbook 2011

Table A-2. Summary Statistics for Selected Islands, Globally

Country	kWh Produced	Oil Consumption (bbl/day)	Natural Gas Consumption (cu m/yr)	Population	GDP (Purchasing Power Parity)
Indonesia	129,000,000,000	1,115,000	45,200,000,000	245,613,043	1,030,000,000,000
Malaysia	107,400,000,000	536,000	26,270,000,000	28,728,607	414,400,000,000
Philippines	61,930,000,000	307,200	2,940,000,000	101,833,938	351,400,000,000
New Zealand	42,400,000,000	154,100	4,320,000,000	4,290,347	117,800,000,000
Puerto Rico	23,720,000,000	164,100	806,600,000	3,989,133	64,840,000,000
Cuba	16,890,000,000	169,000	400,000,000	11,087,330	114,100,000,000
Iceland	16,840,000,000	18,900	-	311,058	11,820,000,000
Dominican Republic	14,020,000,000	118,000	470,000,000	9,956,648	87,250,000,000
Sri Lanka	9,901,000,000	90,000	-	21,283,913	106,500,000,000
Jamaica	7,324,000,000	77,000	-	2,868,380	23,720,000,000
Trinidad and Tobago	7,202,000,000	43,000	21,940,000,000	1,227,505	26,100,000,000
Papua New Guinea	2,885,000,000	36,000	100,000,000	6,187,591	14,950,000,000
Mauritius	2,321,000,000	23,000	-	1,303,717	18,060,000,000
Bahamas, The	2,045,000,000	36,000	-	313,312	8,921,000,000
New Caledonia	1,825,000,000	13,000	-	256,275	3,158,000,000
Madagascar	1,045,000,000	21,000	-	21,926,221	19,410,000,000
Barbados	1,003,000,000	9,000	29,170,000	286,705	6,227,000,000
Fiji	928,000,000	11,000	-	883,125	3,869,000,000
Aruba	850,000,000	8,000	1	106,113	2,258,000,000
Virgin Islands	776,400,000	88,820	-	109,666	1,577,000,000
Bermuda	675,600,000	5,000	-	68,679	4,500,000,000
French Polynesia	650,000,000	7,000	-	294,935	4,718,000,000
Haiti	650,000,000	12,000	-	9,719,932	11,480,000,000
Cayman Islands	546,000,000	3,000	-	51,384	2,250,000,000
Maldives	542,000,000	6,000	-	394,999	2,734,000,000
Saint Lucia	325,000,000	3,000	-	161,557	1,798,000,000
Saint Maarten	304,300,000	#N/A	#N/A	37,429	794,700,000
Faroe Islands	275,800,000	5,000	-	49,267	1,590,000,000
Seychelles	250,000,000	7,000	-	89,188	2,053,000,000
Cape Verde	250,000,000	2,000	-	516,100	1,908,000,000
Micronesia, Federated States of	192,000,000	#N/A	#N/A	106,836	238,100,000
American Samoa	185,000,000	4,000	-	67,242	575,300,000

Country	kWh Produced	Oil Consumption (bbl/day)	Natural Gas Consumption (cu m/yr)	Population	GDP (Purchasing Power Parity)
Grenada	178,700,000	3,000	-	108,419	1,098,000,000
Saint Vincent and the Grenadines	133,800,000	2,000	-	103,869	1,069,000,000
Saint Kitts and Nevis	130,000,000	1,000	-	50,314	684,000,000
Antigua and Barbuda	110,000,000	5,000	-	87,884	1,425,000,000
Samoa	109,000,000	1,000	-	193,161	1,055,000,000
Solomon Islands	71,000,000	2,000	-	571,890	1,627,000,000
British Virgin Islands	45,000,000	1,000	-	25,383	853,400,000
Tonga	43,000,000	1,000	-	105,916	751,000,000
Vanuatu	42,000,000	1,000	-	224,564	1,137,000,000
Cook Islands	31,000,000	1,000	-	11,124	183,200,000
Nauru	31,000,000	1,000	-	9,322	60,000,000
Comoros	22,000,000	1,000	-	794,683	800,000,000
Montserrat	22,000,000	1,000	-	5,140	29,000,000
Sao Tome and Principe	19,000,000	1,000	-	179,506	311,000,000
Falkland Islands (Islas Malvinas)	16,000,000	-	-	3,140	105,100,000
Kiribati	14,000,000	-	-	100,743	618,000,000
Turks and Caicos Islands	12,000,000	#N/A	-	44,819	216,000,000
Saint Helena, Ascension, and Tristan da Cunha	8,000,000	-	-	7,700	18,000,000
Niue	3,000,000	-	-	1,311	10,010,000
Northern Mariana Islands	60,600	#N/A	#N/A	46,050	900,000,000

Data source: CIA Factbook 2011[16]

[16] All data from CIA Factbook Comparative Country Statistics. https://www.cia.gov/library/publications/the-world-factbook/rankorder/rankorderguide.html. Accessed March 19, 2012.

Appendix B: Overview of Select NREL Island Energy Initiatives and Collaborations

Hawaii Clean Energy Initiative (HCEI)

The HCEI aims to transform Hawaii into a world model for energy independence and sustainability. The state's goal is to meet 70% of its energy needs with clean energy by 2030; 30% will be achieved through efficiency improvements, and 40% will be from renewable energy sources. In January 2008, the HCEI partnership officially commenced with the signing of a memorandum of understanding between DOE and the governor of Hawaii. Since that time, DOE has provided significant time, expertise, and funding to assist Hawaii in developing strategies to achieve their goals. NREL is managing this assistance through on-site full-time support; developing and coordinating stakeholder interactions; analysis of energy efficiency, renewable energy, and transportation opportunities; policy and regulatory analysis; and outreach and education initiatives.

Beginning in 2008, the HCEI appointed working groups of key stakeholders from across the state to devise strategy and policy in four domains: electricity, end-use efficiency, transportation, and fuels. These working groups identified a range of strategies toward achieving the HCEI targets, as outlined in Figure B-1. These strategies play an important role in establishing ambitious targets, as well as providing a level of focus and aggressiveness for the working groups.

Electricity Sector *40% Renewable Energy (RE) by 2030*	**Efficiency Sector** *30% Greater Energy Efficiency by 2030*	**Transportation Sector** *Displace 70% Petroleum by 2030*	**Fuels Sector** *Meet In-State Demand for Renewable Fuels*
Strategies: • Align regulatory and policy framework with clean energy goals • Increase process certainty in developing new RE • Deploy RE and grid infrastructure • Explore next gen technologies and new applications	**Strategies:** • Align regulatory and policy framework • Retrofit residential and commercial buildings • Strengthen new constructions policies / building codes • Identify non-building related energy efficiency measures	**Strategies:** • Accelerate electric and hydrogen vehicle infrastructure and deployment • Increase renewable fuel use in the transportation sector • Improve vehicle fleet efficiency • Reduce vehicle miles traveled	**Strategies:** • Support development of local agricultural industry • Invest in key infrastructure at scale • Evaluate and develop renewable fuel processing infrastructure • Match potential fuel supply with in-state demand

Figure B-1. The four strategic areas and working groups of the Hawaii Clean Energy Initiative

Source: Hawaii Clean Energy Initiative

Hawaii has conducted significant analysis on the economic impact of fossil fuel dependence. More than 80% of Hawaiian electricity generation is fossil fuel based, and the import of fossil fuels comprises a

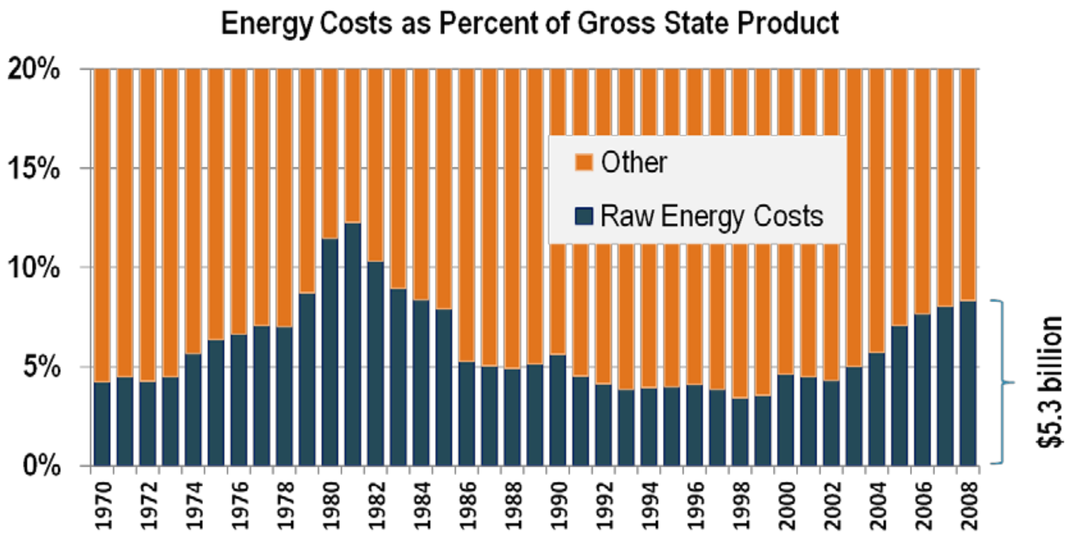

Figure B-2. Energy costs as a share of Hawaii gross state product

significant portion of the state's economic activity, as shown in Figure B-2.[17] Progress toward the 40% renewable energy goal is shown in Table B-1.[18]

Table B-1. Status of RETs as a Percentage of Hawaii Electricity Generation, 2009

2009 Renewable Energy Generation Percentages	Hawaiian Electric Company/ Maui Electric Company/Hawaii Electric Light Company	Kauai Island Utility Cooperative
Total MWh Sales	9,689,661	469,507
Renewable Gen MWh	892,866	38,583
Renewable Percentage	10%	9%
MWh Need to Reach 40% Renewable Generation	2,953,001	144,197

One of the first actions of the HCEI was to establish programs and incentives to encourage the installation of solar thermal water heaters. The growing role of this technology is shown in Figure B-3.[19]

[17] Hawaii Department of Business, Economic Development, and Tourism, Databook. 2010. http://hawaii.gov/dbedt/info/economic/databook/db2010/. Accessed March 20, 2012.
[18] Hawaii Department of Business, Economic Development, and Tourism Databook. 2010. http://hawaii.gov/dbedt/info/economic/databook/db2010/. Accessed March 20, 2012.
[19] Hawaii Department of Business, Economic Development, and Tourism. 2011. Presentation by Maria Tome, Transportation & Renewable Energy Program Manager. Data from Honeywell Utility Solutions; Hawaii Energy Efficiency Program; KIUC.

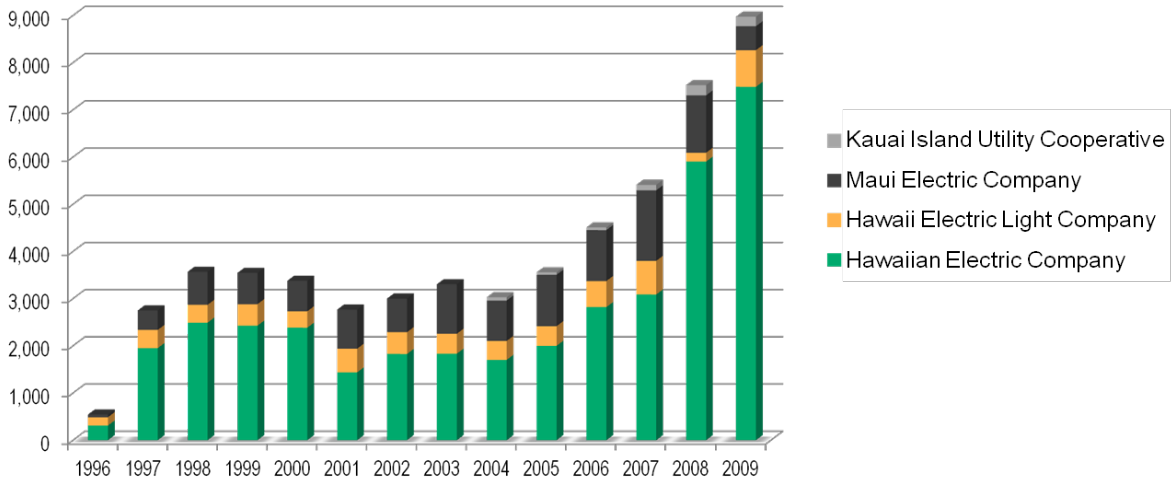

Figure B-3. Annual installations of solar water heaters[19]

U.S. Territories: Guam, Central and Northern Mariana Islands, and American Samoa

The U.S. Department of Interior (DOI), Office of Insular Affairs (OIA) has administrative responsibility for coordinating federal policy in the territories of American Samoa, Commonwealth of the Northern Mariana Islands, and Guam. Under an interagency agreement funded by DOI's OIA, NREL was tasked to provide technical assistance to the Pacific Territory Governments of American Samoa, Commonwealth of the Northern Mariana Islands, and Guam by conducting an initial technical assessment that details current energy consumption and production data to establish a baseline, initial energy efficiency and renewable energy (EE/RE) opportunity assessments, support for establishing energy steering committees and subcommittees for prioritization and implementation of energy programs and projects, and assistance in developing a strategic plan for EE/RE implementation and deployment. NREL is providing an interdisciplinary team to assess opportunities for integrated wind-diesel generation, energy efficiency and building technologies, solar PV and hot water, biomass and WTE, and geothermal electricity generation. The intent is to provide the territories with approaches to deploying cost-effective EE/RE technologies in a manner that meets short-term needs, integrates with existing systems, and helps meet the longer-term energy objectives of each territory. Initial energy assessment reports have been developed for each territory, and NREL is working with the energy steering committees to develop goals for EE/RE penetration and fossil fuel reduction.

Partnership with Okinawa Prefecture

Based on an interest to build on the experience of the HCEI, the State of Hawaii, the Prefecture of Okinawa, the DOE, and the Ministry of Economy, Trade and Industry of Japan signed a Memorandum of Cooperation in June 2010, which created the Hawaii-Okinawa Partnership on Clean and Efficient Energy Development and Deployment. The objectives of the partnership include determining how to transition Hawaii and Okinawa to clean energy economies; a bi-lateral exchange of expertise and information on deployment best practices; demonstration of energy efficiency and renewable energy technologies, financing methods, enabling policies, and leadership; and establishing a network of experts for continued collaboration to achieve their clean energy goals. The partnership has established an exchange of technical expertise and is currently working to identify joint projects to undertake.

Millennium Challenge Corporation Compact with Indonesia

Indonesia, the most populous island chain in the world, is conducting a wide range of energy development efforts to improve access to electrical power by its citizens. Recognizing the Government of Indonesia's (GOI) emphasis on sustainable "green" economic growth, the U.S. government's Millennium Challenge Corporation in 2011 finalized a Compact with the GOI. Within the Compact, the Green Prosperity program commits on the order of US $300M to promote low-carbon economic development activities that have a focus on clean energy, improved natural resource management practices, and sustainable land use. The program is designed to support Indonesia's long-term sustainable development goals by identifying and facilitating robust, sustainable projects meeting technical, economic, environmental, and social criteria. The primary purpose of this Compact, recognizing the strong correlation between poverty and environmental degradation, is to reduce poverty through economic growth, as measured by increased income of poor households. To achieve these goals, an emphasis is being placed on expanding the use of grid-tied and distributed RETs, including hydro, biomass, biogas, and solar in provinces throughout the archipelago. NREL is providing technical assistance on RE project identification, project screening criteria, operational, and training requirements for various technologies and funding approaches.

Enhancing Capacity for Low Emission Development Strategies in the Philippines

Although endowed with diverse and distributed energy resources, the islands of the Philippines face significant technical and geographical barriers to the production of reliable and low-cost power. A relatively fragile T&D system, a less than functional energy market, and loads spread over hundreds of islands make efficiencies and scale hard to achieve. While still a regional leader in geothermal and having a significant share of large and mini hydro in their energy mix, the majority of recent and anticipated future capacity growth in the Philippines is in more carbon intensive coal and natural gas for utility-scale power and diesel for smaller-scale distributed systems. With a stated goal of tripling renewable energy capacity, including hydropower, from roughly 5 GW to 15 GW by 2030, the Government of the Philippines (GPH) has aggressive but achievable targets based on their domestic resources in these categories. Achieving these targets will be critical to the Philippines implementing a low carbon growth strategy and representing areas where significant policy, technical, and capacity building support will be required. At the same time, GPH projects a doubling in demand for energy services by 2030 with oil (transport) and coal (electricity) as the primary means to meet that growing demand. A principal challenge will be to meet that goal in a way that ensures affordability, reliability, and resiliency but does so in a less carbon intensive manner over the long term. The U.S. government's Enhancing Capacity for Low Emission Development Strategies (EC-LEDS) program will provide technical assistance to the GPH as they accelerate the use and deployment of renewable energy to meet these targets including mini-grid opportunities to meet their significant distributed loads on rural islands.

A notable outcome of recent work is the Philippines Power Development Plan, developed by the DOE in 2010. This comprehensive plan prioritizes energy security, energy sector reform, and sustainability. Energy security is emphasized both in terms of improved reliability, particularly in the South, and energy self-sufficiency to promote less exposure to price fluctuations in liquid fuels for transportation and other imported fuels. Although continued expansion in the coal capacity is assumed through 2030, cost-effective development of less carbon-intensive energy technologies including renewables and natural gas for electricity generation are included along with conservation and alternative fuels (with aggressive targets for blending requirements).

Partnership with the Organization of American States

In 2009, DOE and OAS partnered in a joint effort to engage seven Caribbean countries, namely St. Lucia, Dominica, Grenada, St. Kitts and Nevis, the Bahamas, Antigua and Barbuda, and St. Vincent and the Grenadines. These seven project countries face critical challenges with regard to the generation, delivery, and consumption of energy, as all are highly dependent on imported fossil fuels. The project seeks to improve the sustainability of the energy sector of the eastern Caribbean countries by fostering a transition away from energy consumption and supply patterns based on fossil fuels, towards systems based on renewable energy and energy efficiency technologies and systems.

NREL is working closely with OAS, local energy offices, governments, and utilities to address the barriers to deploying energy efficiency and renewable energy in the islands. NREL has conducted a hands-on energy auditing training; is developing and hosting a Caribbean Energy Workshop focused on renewable energy, energy efficiency, transportation, and strategic energy planning; and will work with OAS to develop a targeted renewable energy resource assessment strategy for these island nations.

Haiti Energy Working Group

NREL is working with the DOE Office of Energy Efficiency and Renewable Energy to support the U.S. Government Haiti Energy Working Group led by the U.S. Department of State. DOE funded NREL to conduct an initial technology screening and high resolution resource mapping to inform renewable energy decision making and identify opportunities for assessment of renewable integration into the current or future electrical system. This has resulted in NREL funding from the U.S. Agency for International Development to develop detailed feasibility studies for wind power development near Cap Haïtien (as part of the North Industrial Park development) and the Hispaniolan Rift Valley and a partnership with the United Nations Environment Programme and United Nations Office for Project Services to perform a feasibility analysis for a waste-to-energy plant in Port-au-Prince. The feasibility analysis will determine specific project opportunities, system sizes and renewable energy penetration potential, economics, risks and risk mitigation strategies, and educational requirements.

Low Carbon Communities in the Caribbean Project

The Low Carbon Communities in the Caribbean project is led by the Organization of American States (OAS) and the DOE to implement actions and strategies geared towards increasing the sustainability of the islands' energy supplies while reducing carbon emissions from the energy sector through the development and use of renewable energy and energy efficiency systems. The project seeks to develop the local workforce to conduct energy efficiency audits, deploy energy efficiency technologies, and strengthen the capacity to review and evaluate resource assessments related to renewable energy resources.

Energy Development in Island Nations

The international partnership for Energy Development in Island Nations (EDIN) aims to advance the deployment of renewable energy and energy efficiency technologies in islands across the globe. The EDIN partnership was formed by Iceland, New Zealand, and the United States in 2008, and a steering committee comprising representatives of the three countries holds bimonthly teleconferences and meets annually to set priorities, review progress, and plan future activities. The DOE coordinates U.S. involvement in EDIN, with NREL serving as the Secretariat for the organization. EDIN participants are currently engaging in pilot projects to test approaches and methodologies with the aim of establishing replicable models. Under this partnership, New Zealand has performed a desktop study of geothermal potential for the Pacific, and the United States is providing multi-year technical support to the USVI effort to reduce fossil fuel consumption by 60% by 2025. In the Pacific, EDIN held an Island Energy Symposium in the Commonwealth of the Northern Mariana Islands in October 2010, which was attended by over 60 participants from island governments, energy offices, utilities, universities, and regional development banks. This symposium focused on specific technology applications for island communities and peer-to-peer information exchange.

U.S. Virgin Islands

Under EDIN, DOE is working through NREL to provide comprehensive technical and policy support to the USVI in support of the territory's goal of reducing fossil fuel use by 60% by 2025; the lessons learned in this project, along with HCEI, will apply to islands worldwide. The USVI has abundant renewable energy resources that, along with energy efficiency measures, offer a potential solution to address the territory's total dependence on imported fossil fuels. NREL has teamed with DOE, DOI, and the USVI Energy Action Team to provide technical assistance needed to meet their goals. Five working groups in USVI are focused on the following areas: (1) policy and analysis, (2) renewable energy development and integration, (3) energy efficiency, (4) transportation, and (5) education and workforce development. NREL is providing technical assistance and energy analysis to determine the most appropriate and achievable technology mix, strategies for financing and deployment, and training and outreach. This work is being conducted in close collaboration with the utility, the governor's office, local advocacy groups, and the private sector.

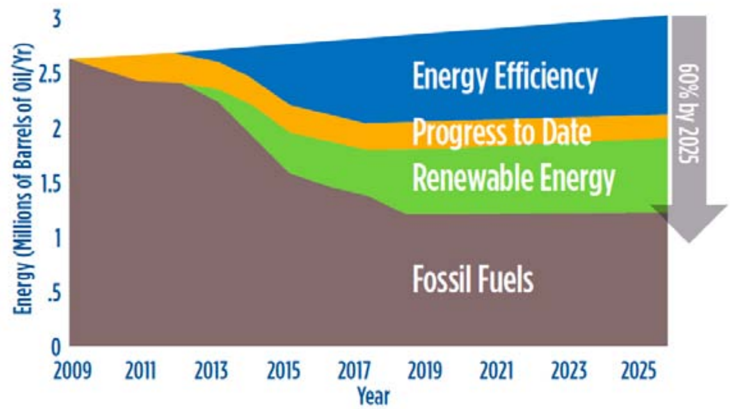

Figure B-4. USVI goal of 60% reduction by 2025

As with many policymakers in island settings, the sheer range of solutions available to the USVI planners can be bewildering. NREL undertook analysis to rank and prioritize energy efficiency and renewable energy tactics that can help the USVI reach their goals. The resulting supply curve is discussed in Section 3.

Across various technology areas, the USVI project collaboration produced several notable achievements in 2010 and 2011:

Solar

- Updated solar resource maps
- Implemented a SWH rebate and loan program
- Received loan applications for over 500 SWH systems (April 2010–April 2011)
- Implemented a net-metering program mandated by Act 7075
- Installed 176 kW of small PV systems
- Installed a 448 kW solar PV system—the largest in the region—at Cyril E. King Airport

- Supported the local utility in the procurement of over 10 MW of solar PV via several power purchase agreements

Wind

- Developed low-resolution wind maps
- Identified sites with high potential for utility-scale wind
- Signed contracts to install wind anemometers and sonic detection and ranging (SODAR) systems in the USVI

Biomass, landfill gas, and WTE

- Identified potential for approximately 2 MW of energy generated from landfill gas
- Supported development of 800 kW landfill gas system
- Developed biomass crop-potential maps
- Completed biomass chemical and heat content analysis

Fernando de Noronja island, Brazil

Fernando de Noronja is an archipelago consisting of 21 islands off the northeastern coast of Brazil with a population of approximately 3,400 people. USAID funded NREL to perform a comprehensive assessment of near-term and longer-term energy efficiency and renewable energy opportunities to reduce fossil fuel consumption. Renewable energy generation options assessed included wind, PV, SWH, biofuels, and ocean technologies. Immediate opportunities include PV, wind, solar water heating, and water conservation; energy efficiency programs and additional wind and PV are recommended for further analysis.